A man who is not afraid of the sea will soon be drowned, he said, for he will be going out on a day he shouldn't. But we do be afraid of the sea, and we do only be drowned now and again.

John Millington Synge, *The Aran Islands*, in Auerbach: Wilderness Medicine

Cold Water Immersion Injuries and Anesthetic Implications

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Objectives

- Case report
- Definitions
- Epidemiology
- Pathophysiology
- Expose some myths about drowning
- Management – field, ER, OR, ICU
- Use of cardiopulmonary bypass
- Future advances
- Recent references

Case Report

- It is a cold day in January and you are on call at Washington Hospital Center (heart month)
- The call comes in that a young female was witnessed slowly driving her car into the Potomac river, windows down, watching the emergency vehicles on the shore as the car sank to the bottom
- She arrives at the ER and you are one of the first responders
- Core temp is 17 C; asystolic

Questions that come to mind

- She is cold, unresponsive, and without a rhythm – is she dead?
- If not, do you start/resume/continue CPR?
- Does it matter if the immersion was salt or freshwater?
- Is a diuretic (lasix) indicated for pulmonary edema?
- What is the preferred method of ventilation?
- Is it possible to drown without water in the lungs?
- How do you get her warm again?
- Is cardiopulmonary bypass indicated? But first …

You urgently need new epidural/PCA pumps, you have funding and finally got the

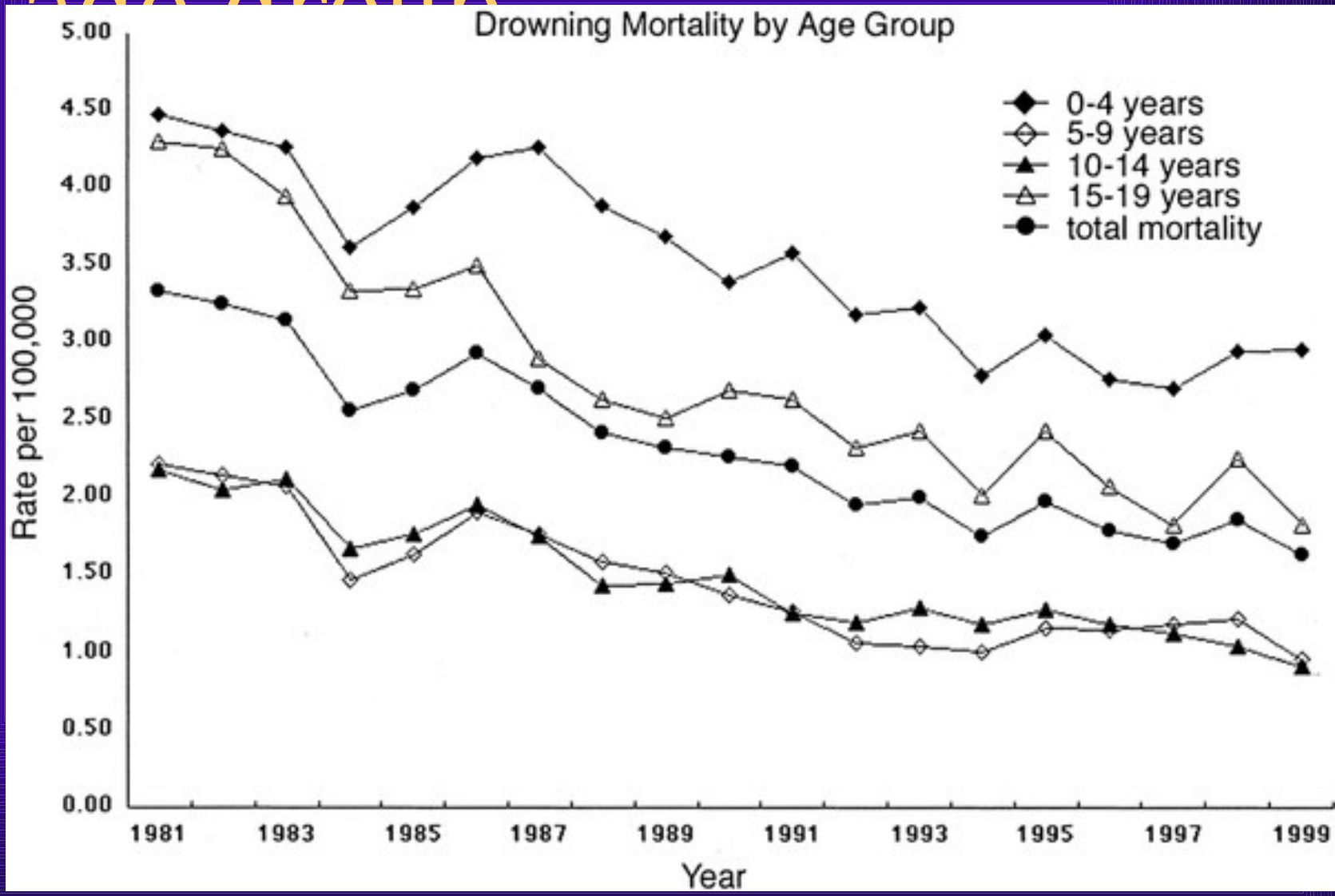
Definitions

- ***Drowning:*** suffocation by immersion or submersion in any liquid medium, caused by the entrance of liquid into the airways, that partially or fully compromises ventilation or oxygen exchange
- ***Submersion incident:*** a person who is adversely affected by being submersed in water
- ***Immersion syndrome:*** (immediate disappearance syndrome) syncope provoked by bradycardia, tachycardia, or arrhythmia precipitated by sudden contact with water at a temperature at least 5 C less than body temperature (Orlowski)

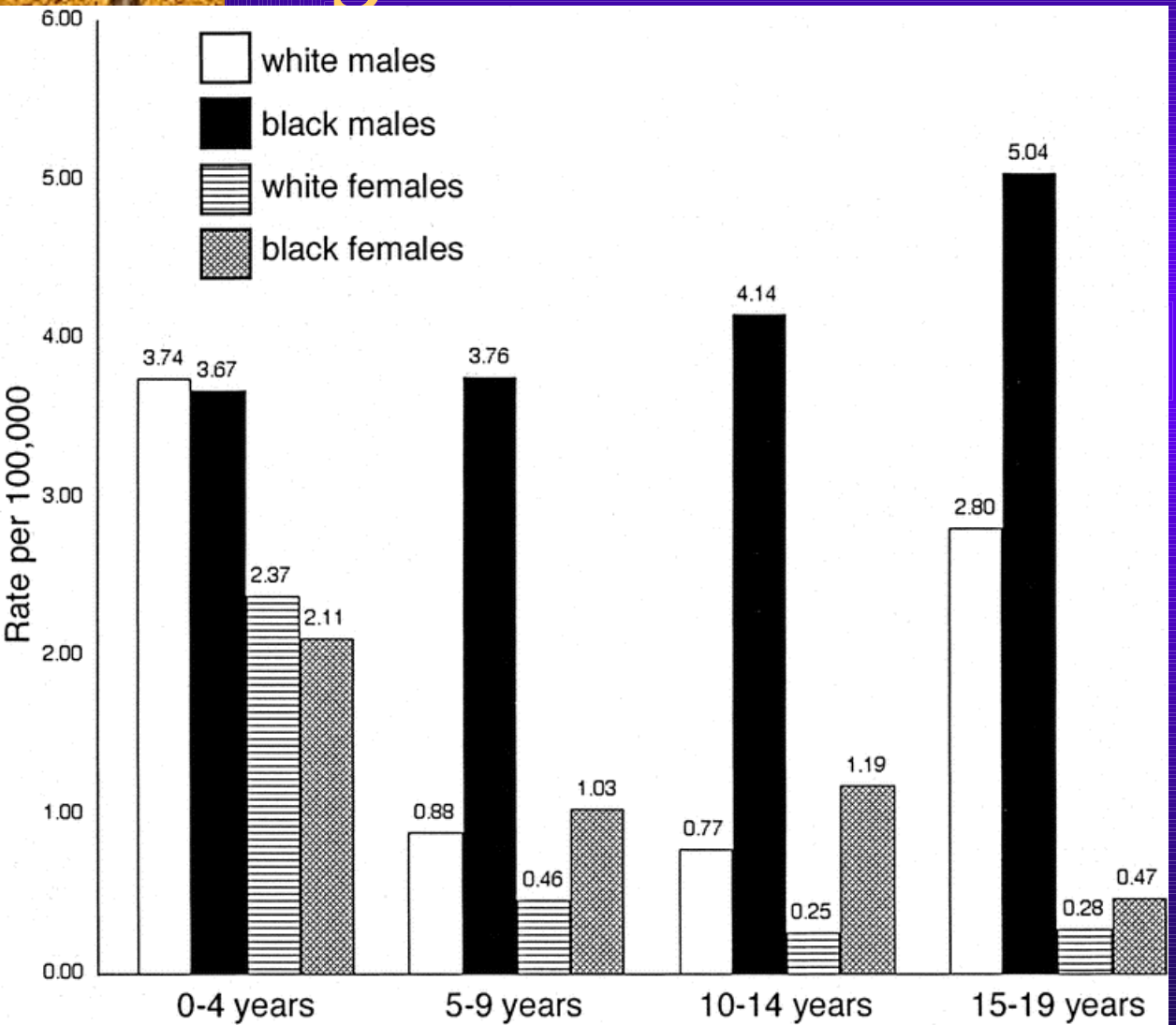
Epidemiology of Submersion Incidents

- Estimated to be 31,000 ER visits, 8000 hospitalizations, and 4500 deaths (1999)
- Highest for toddlers and teenage boys
- Rates have been improving with improved awareness and prevention measures
- One of the leading causes of death for all age categories and is higher worldwide
- Common sites include oceans or estuaries (22%), private swimming pools (17%), nontidal lakes and lagoons (17%), surfing beaches (10%), and bathtubs (7%)

Drowning mortality by age group



Drowning mortality by age/race/sex



- Swimming ability
- Parent's swimming ability
- Location of swimming
- Availability of lifeguards
- Frequency of swimming
- Risk-taking behavior

(Ibsen)

Other Factors

- Alcohol or drugs (64% of male deaths)
- CVA, seizure, MI, long QT syndrome
- Trauma – diving, falls, horseplay
- Child abuse
- Hypothermia
- Hyperventilation: $PaCO_2$ decreases with minimal PaO_2 increase – PaO_2 can decrease enough to cause cerebral hypoxia and loss of consciousness prior to $PaCO_2$ rising enough to cause an urge to breathe.

But at least they are paying attention …

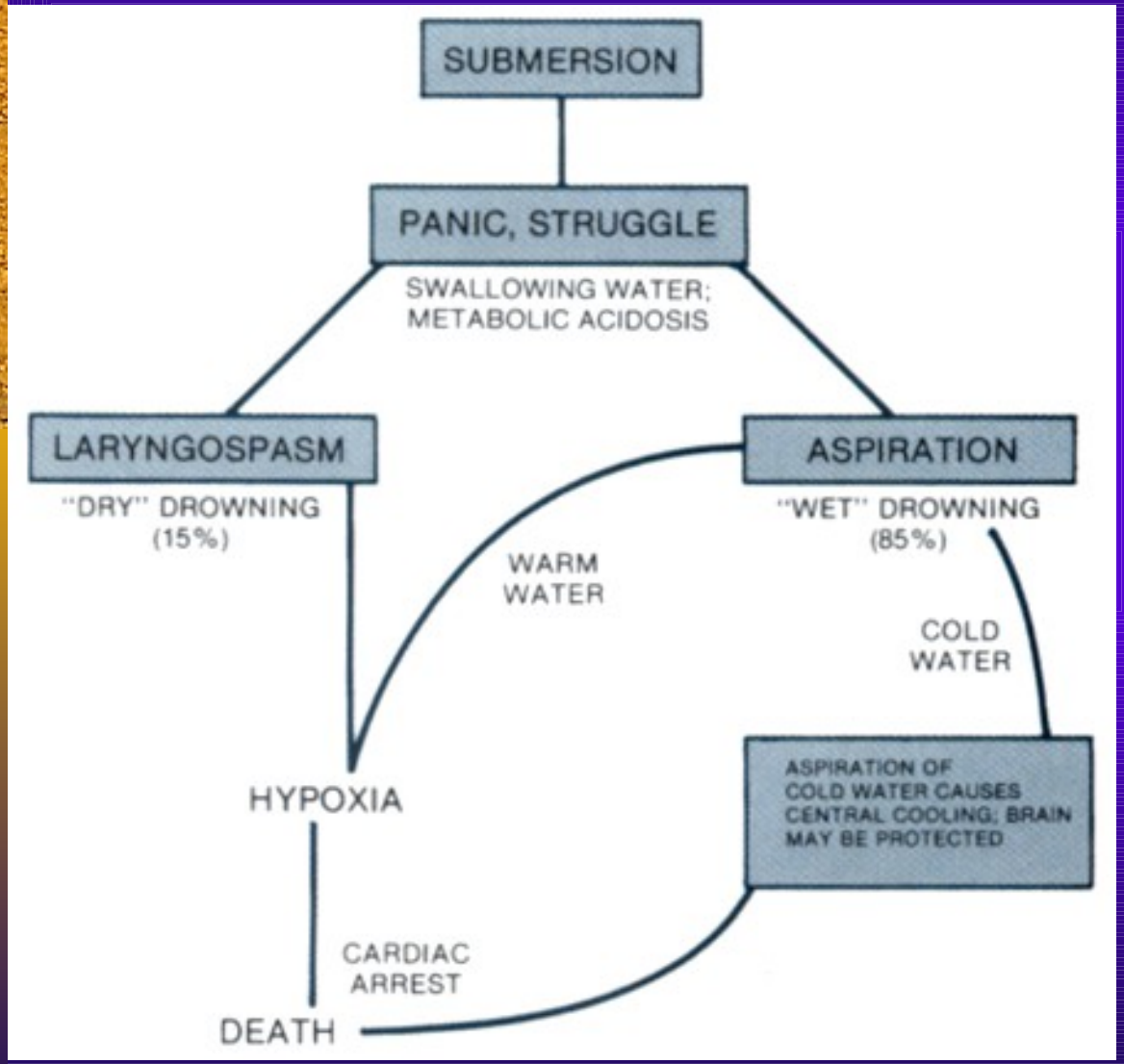
- Substitute “program” for

Associated Injuries

- Full trauma evaluation, especially with boating, diving, or water sport activities
- MYTH: all drowning victims need c-spine stabilization
- REALITY: Little evidence to support c-spine immobilization without a history of trauma
- Prevalence of c-spine injuries in immersion injuries is low (0.5%) and all of those had clinical signs of serious injury and a history of high-impact trauma prior to/during immersion (boating accident, diving in shallow water) (Ibsen)

Progression of drowning

(Auerbach)



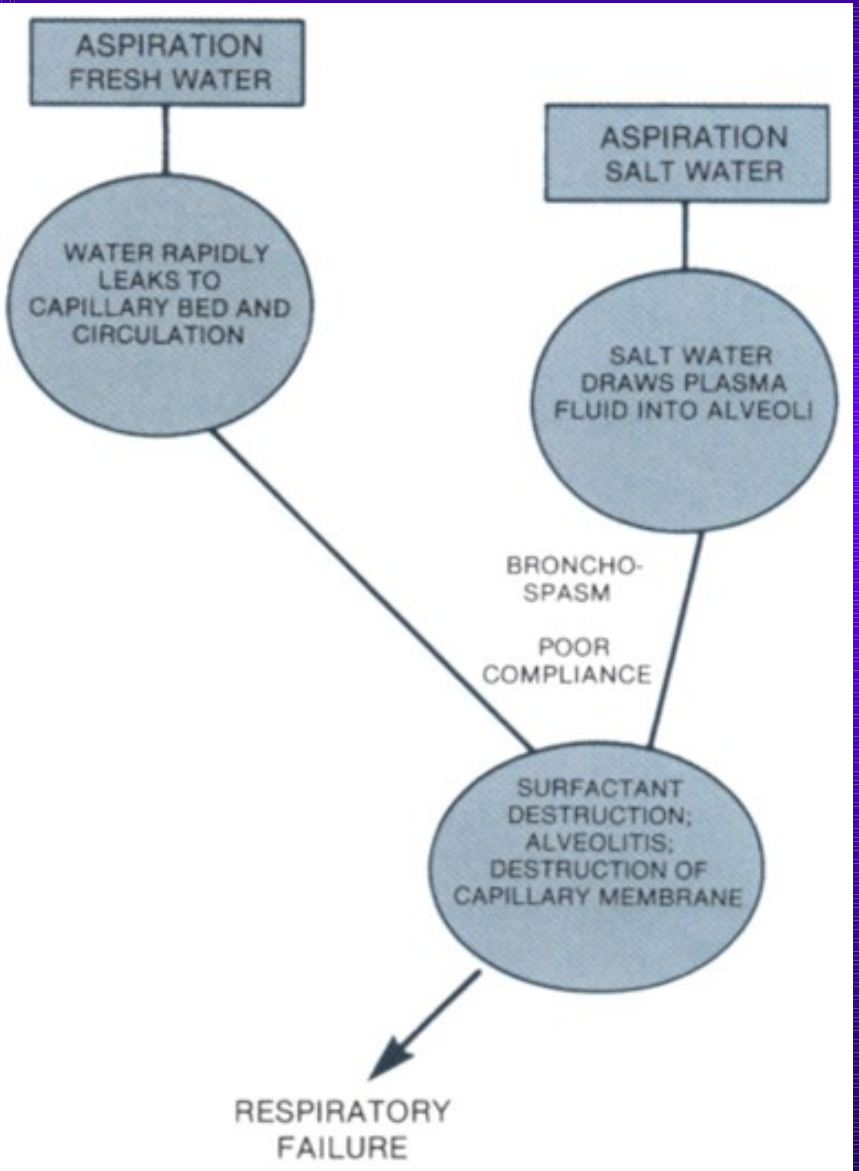
- Small fluid volume actually aspirated
- Large volumes are swallowed
- M/M associated with pulmonary and cerebral hypoxia

Myth: saltwater vs. freshwater makes a difference

- ANIMAL STUDIES:
- Freshwater: aspirated hypotonic fluid passes rapidly through lungs, causing hypervolemia, dilution of electrolytes, and hemolysis
- Saltwater: aspirated hypertonic fluid draws fluid in alveoli creating pulmonary edema and concentration of electrolytes
- THIS HAS NOT BEEN SEEN IN HUMANS. Those who survive rarely have aspirated enough fluid to cause these changes; hypoxia is the critical factor.
- Chlorine at a concentration found in pools has no impact on degree of injury (Olshaker, Ibsen, Orlowski)

Pulmonary effects

(Auerbach)



- Abnormal surfactant function: alveolar collapse, atelectasis, intrapulmonary shunting, ventilation-perfusion mismatch.
- Damage to alveolar-capillary membrane
- Seen as noncardiogenic pulmonary edema – ARDS
- Stiff, noncompliant lungs
- Can change rapidly, even if appears clinically well

Neurologic pathophysiology (Ibsen)

- Hypoxia and cardiac arrest lead to brain tissue hypoxia, acidosis, diffuse cerebral edema, elevation in ICP. Experimental differences in ischemia and hypoxia.
- Ischemia leads to elevation in extracellular glutamate concentrations – neuronal damage
- However, even severe hypoxia without ischemia does not lead to elevated glutamate levels or pathologic changes
- Greatest susceptibility in vascular end zones (“watershed areas”)

Cardiovascular pathophysiology

- Secondary to hypoxia, acidosis from pulmonary injury.
- Low cardiac index, elevated R and L heart filling pressures, elevated SVR and PVR
- Supraventricular tachycardias common; increased catecholamines
- Generally reversible depending on effectiveness of resuscitation, duration of hypoxia, and hypothermia
- Permanent myocardial dysfunction rare; autopsies suggest some coronary artery spasm and focal myocyte injury

Other systems

- Renal: in severe cases can have acute tubular necrosis from hypoxia; shock/acidosis can increase severity
- Hematological: No acute changes; rare DIC in the ICU
- Metabolic: minimal electrolyte changes; will see respiratory acidosis, metabolic acidosis
- General rule: if you are seeing any of these changes, the initial injury is not survivable

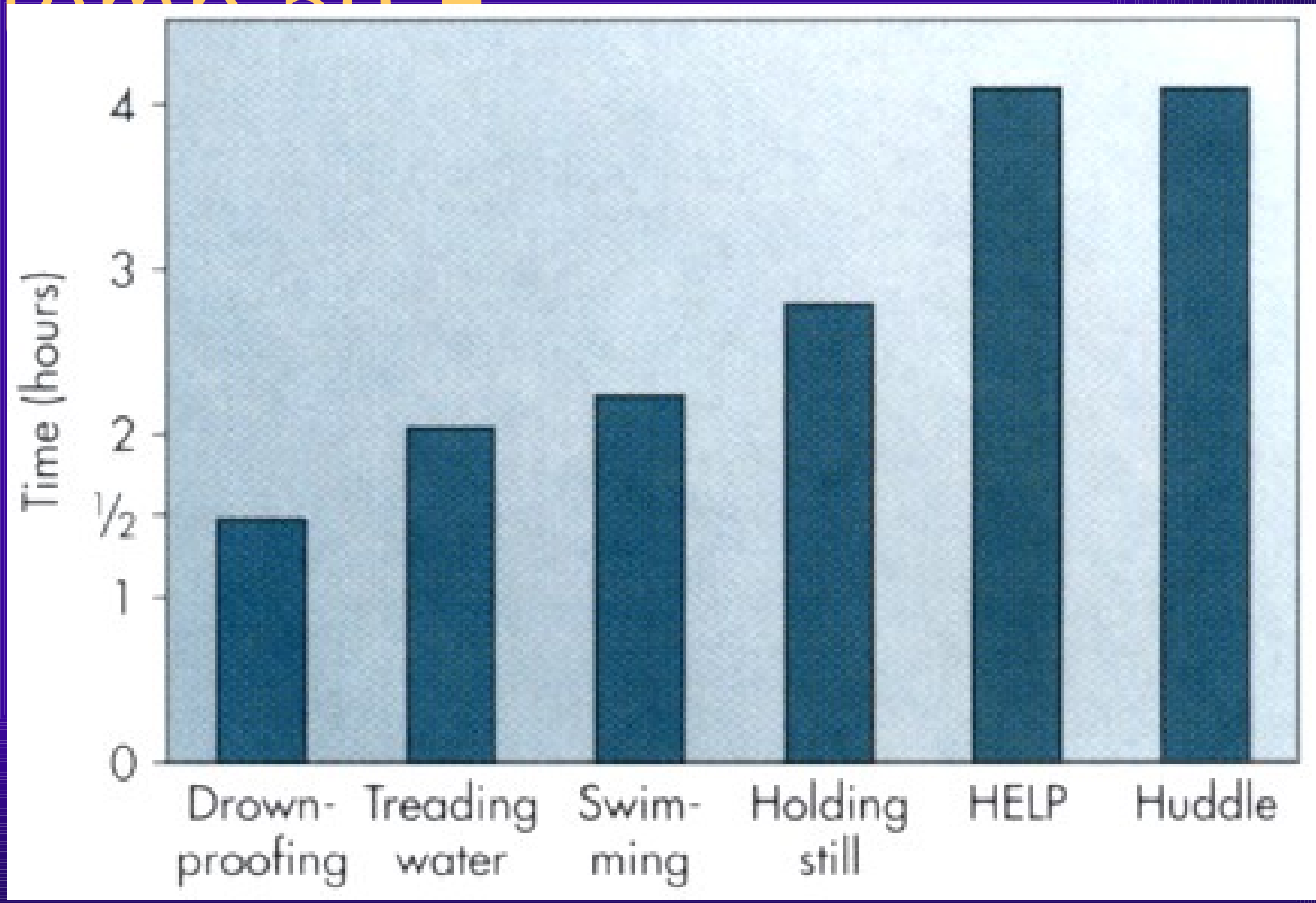
New initiatives always have their distracters …

- Substitute “program” for “[illegible]”

Hypothermia

- Generally adverse effects: arrhythmias, quick exhaustion, coagulopathy, immune cell function, worse outcomes
- Moderate (32-35 C): increased sympathetic tone, shivering, increased oxygen consumption
- 28-32 C: shivering stops, HR/BP/O2 use decreases
- Less than 28 C: bradycardia, spontaneous ventricular fibrillation, asystole
- Do not make final survival decisions until rewarmed due to rare revivals unless obviously dead (rigor mortis, putrefaction, dependent lividity)

Survival times, water temp 50 F



HELP position

- Heat Escape Lessening Posture
- Must have life vest
- Keep still, keep head out of water
- Arms across chest and pressed to sides, knees drawn to chest, ankles crossed
- Very fatiguing
- Modification shown on left

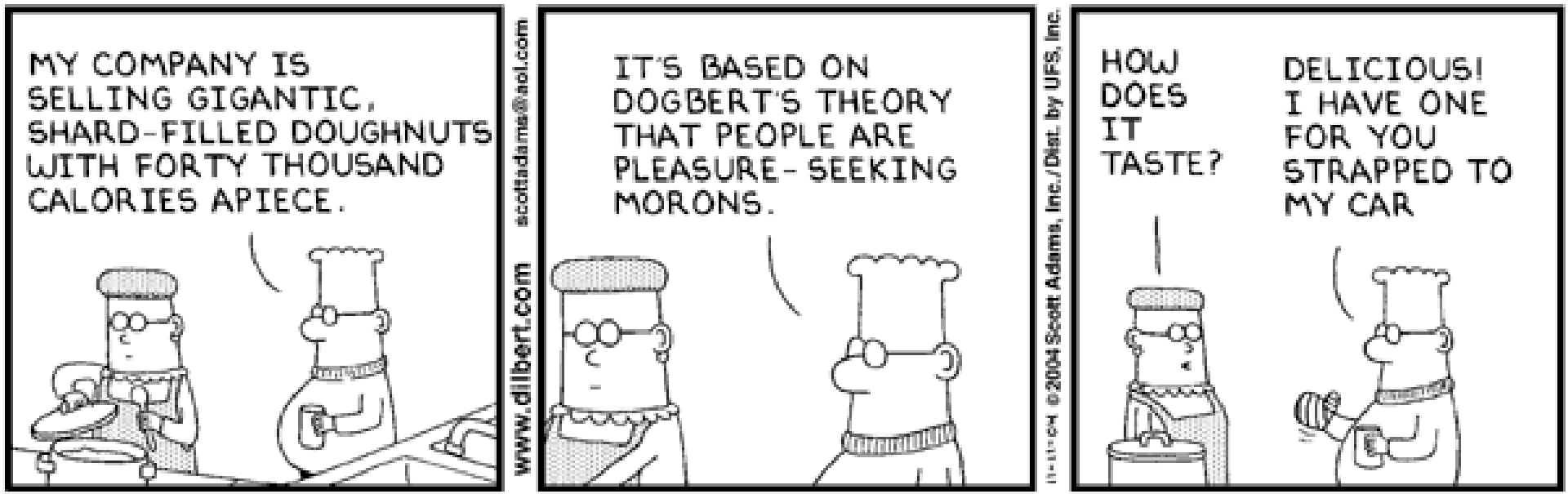
Huddle position

- Two or more people
- Place children in the middle
- Connect life vests in the back

Hypothermia can (rarely) be beneficial

- “Dive reflex”: in mammals occurs when cold water comes in contact with the face. Breath-holding, peripheral vasoconstriction, bradycardia and reduced cardiac output, increased MAP, selective perfusion of heart and brain.
- Delay hypoxic adverse effects by reducing the metabolic demands of the body
- Blunting of catecholamine release (less Vfib)
- Reduced muscle movement and metabolic acidosis
- Rare survival with total submersion and arrest with very rapid cooling – generally only in icy conditions and with children (fall through ice)

Of course, this doesn't apply to the food supplied



Cold water rescue (Auerbach, Orlowski)

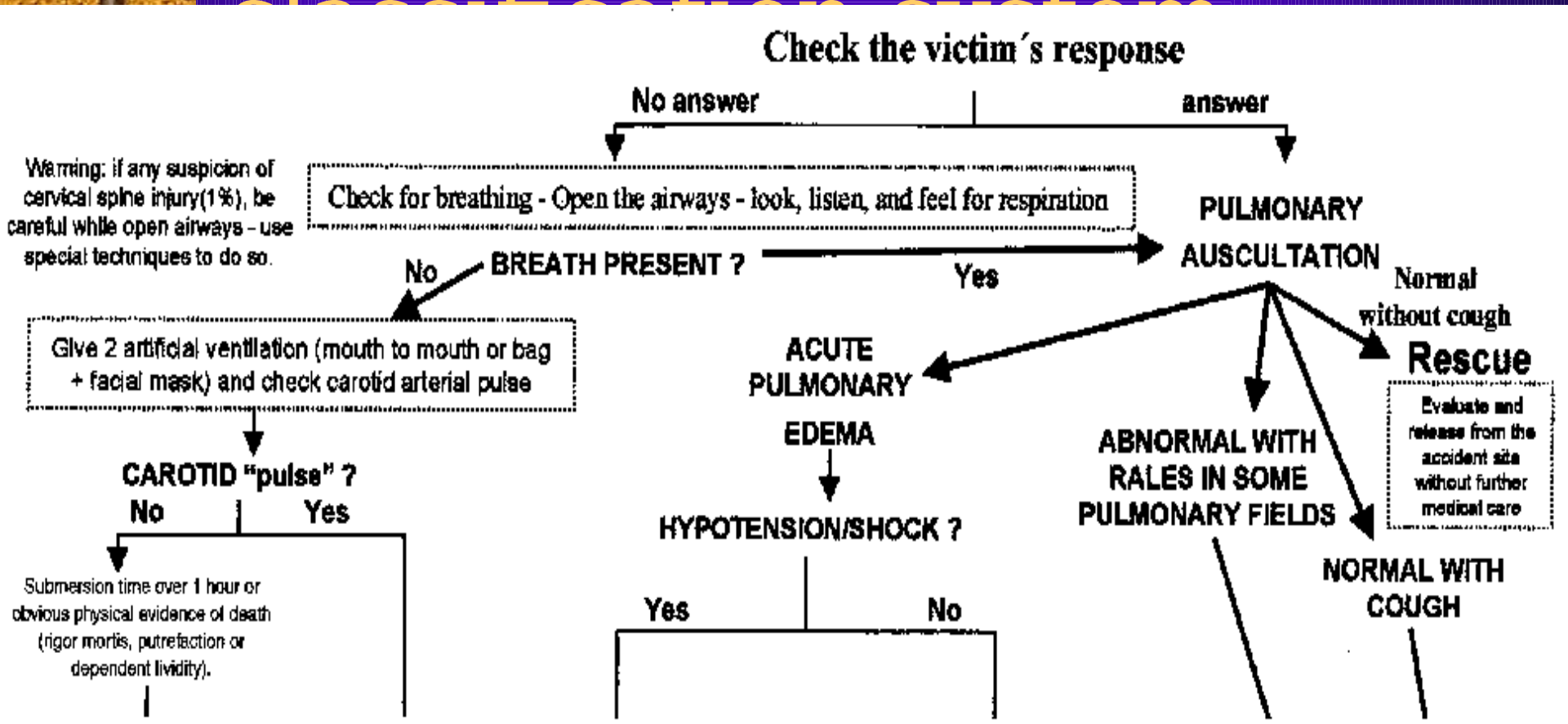
- MYTH: the victim waves and calls for help
- REALITY: Instinctive drowning response: struggling, unable to breathe or call for help
- Children: 10-20 sec of struggling with several surfacings prior to final submersion
- Adults: up to 60 sec
- Don’t become a victim

Immediate resuscitation

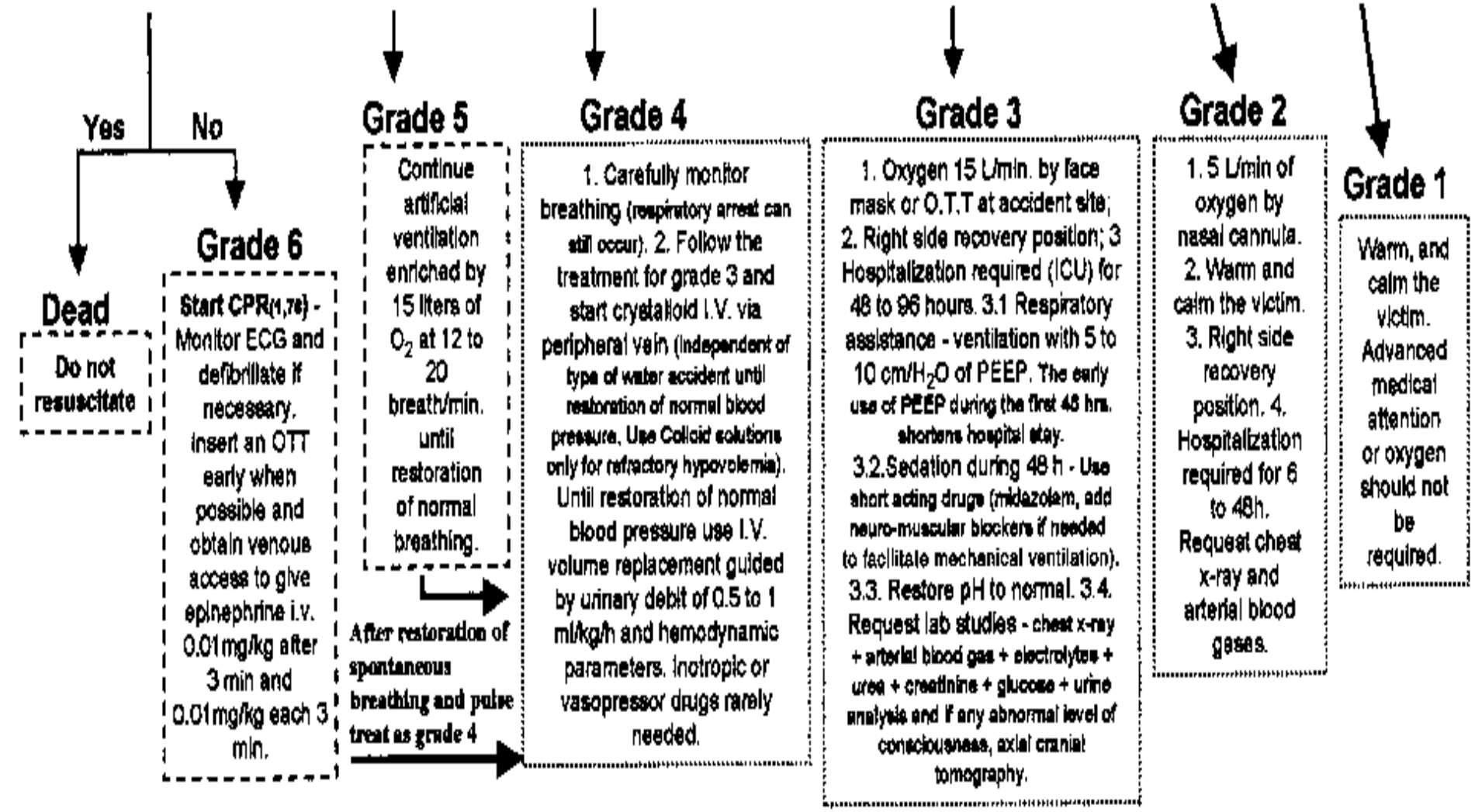
(Auerbach, Orlowski)

- ACLS/ATLS
- Mouth to mouth in the water (50% reduction in mortality if they have a pulse)
- Cardiac compressions once on shore if no pulse
- MYTH: attempt to drain the water from the lungs
- REALITY: High risk of regurgitation and aspiration of gastric contents due to large volume swallowed

Response Algorithm: Szpilman drowning classification system



Response algorithm part 2



DO NOT … (Orlowski)

- Attempt to drain the lungs (e.g. head lower than body while on shore)
- Aspirate foam enthusiastically while ventilating
- Use diuretics or water restriction to treat pulmonary edema
- Use prophylactic antibiotics in the first 48 hours
- Use steroids to treat aspiration and pulmonary edema
- Stop CPR until temp is 34 C
- Provide different ACLS support based on type of water involved in drowning

Additional guidance/OR and ICU

- IV access essential – endotracheally administered drugs difficult to absorb through copious pulmonary edema (may need central line (subclavian?) or cutdown)
- Maintain cricoid pressure prior to intubation if possible
- Ventilate with 5-10 cm of PEEP, increase to 15 if needed. Decreases intrapulmonary shunting, reduces ventilation-perfusion mismatch, increases FRC. Ventilator strategy to minimize lung injury during ARDS (previous topic).
- 100% FiO2 initially, then less than 50% when possible.
- Place NGT and foley
- Active rewarming (a future grand rounds topic); consider CPB for deep hypothermia with arrest
- Consider inotropes, invasive monitors, echocardiography

Severely hypothermic victims

- If temp <28 C and pt has any pulse (severe brady and hypotensive) and respirations, controversial if should intubate and start chest compressions - may precipitate ventricular arrhythmias.
- Rewarming: passive (warm room, dry blankets), active external (forced air, warm blankets, radiant) 0.8 C/hr, shivering 3 C/hr, forced warm air box 6 C/hr; relies on circulation
- Core rewarming: warm IV fluids, heated humidified O2, gastric/bladder/peritoneal lavage. ECMO (2 C/hr) much faster than lavage.
- Cardiopulmonary bypass for profound hypothermia with arrest, 7 C/hr

Late effects – Cerebral ischemia

- Maintain oxygenation and perfusion; may have uncoupling of CBF autoregulation to demand
- Hyperpyrexia common – maintain normothermia
- Barbiturates/controlled hypothermia have not been shown to be beneficial in drowning and increase risk of sepsis.
- MYTH: controlling ICP due to cerebral edema is essential for neurologic outcome
- REALITY: Death or profound neurologic deficits seen if intracerebral edema results in an ICP greater than 20, regardless of the success of therapies to reduce ICP

Prognosis

- No good studies could accurately separate neurologically intact survivors during the acute phase from those who will later die or have profound deficits; serial neuro exams during recovery best predict outcome.
- Unfavorable factors: age 3 years or less, submersed over 5 minutes, no resuscitation for 10 minutes, coma upon arrival to ER, pH 7.1 or less (Orlowski)
- Prolonged CPR, fixed and dilated pupils, GCS of 3 suggest poor outcome (Ibsen)
- 90% survival if arousable with spontaneous respirations 1-2 hours after resuscitation; GCS of 5 upon arrival predicts good neurological outcome
- Bimodal recovery: mostly intact or dead/persistent coma
- These suggest at least a brief attempt at resuscitation for all submersion victims who arrive at the hospital

Anyone listening?

Back to our case report

- CPR and manual ventilation were restarted in ER
- Pt taken to the OR for rewarming (CPR stopped enroute; transporting physician disagreed with continuation of care)
- No liquid visible in airway with fiberoptic scope
- Fem-fem bypass was established and the pt was rewarmed to 36 C
- Spontaneous cardiac electrical activity occurred at approximately 27 C (Vfib)
- Normal sinus rhythm occurred after one defibrillation
- Urine started collecting in the foley
- Able to ventilate with normal pressures and volumes

But it wasn't even close

- Despite the cold water temp, it wasn't icy enough – too long to cool vital internal organs
- Prolonged ischemic time caused irreversible damage
- Reperfusion after rewarming demonstrated end organ damage / ischemic reperfusion injury
- Massive edema throughout body
- Serosanguanous fluid oozing from every pore
- Massive pulmonary edema – unable to suction fast enough. Six liters over the last 10 minutes.
- No activity on BIS monitor
- Efforts ceased when unable to transfer off bypass

Future advancements

- Improved awareness and prevention
- Pushing resuscitation closer to the scene
- Neuroimaging for better prognostication
- Therapies for limiting brain injury: anti-excitotoxic agents, oxygen radical scavengers, lipid peroxidation inhibitors, calcium channel antagonists, glutamate pathway antagonists, NMDA/AMPA/GABA receptor antagonists, glutamate release inhibitors, nitric oxide synthase inhibitors, anti-apoptosis targeted strategies
- Improved use of cardiopulmonary bypass

Resuscitation in near drowning with extracorporeal membrane oxygenation

- Ryalmann, *Ann Thorac Surg*, Aug 2001
- 3 yo female admitted to ER with core temp of 18 C after an icy water immersion in Austria
- Rewarmed on cardiopulmonary bypass, circulation restored. Unable to wean off CPB due to respiratory failure resistant to conventional respiratory therapy.
- Transferred to PICU on extracorporeal membrane oxygenation (ECMO).
- Weaned off ECMO after fifteen hours and required 12 days of mechanical ventilation
- No neurologic deficits after 20 months

Cold water submersion and cardiac arrest in treatment of severe hypothermia with cardiopulmonary bypass

- Wollenek in *Resuscitation*, March 2002
- 3 patients from author's hospital in Austria plus 9 from the literature (9 of 12 survived to hospital discharge)
- Better outcome with lower core temp (mean 20 C, lowest 16 C in survivors; 25 C mean in non-survivors)
- Base excess (-36.5), pH (6.29), or potassium not predictive
- Considered CPB method of choice for resuscitation and rewarming of children with severe accidental hypothermia and cardiac arrest
- Fem-fem cannulation demonstrated inadequate venous drainage in children but not adults – advocate emergency median sternotomy for cannulation

Rewarming from accidental hypothermia by extracorporeal circulation

- Farstad in *Eur J Cardiothorac Surg* Jul 2001
- 26 patients with accidental hypothermia and circulatory arrest or severe failure were rewarmed to normothermia with ECC
- 6 F, 20 M, median 27 yo, 1987-2000
- 17 in cold water, 1 avalanche, 8 prolonged exposure to cold surroundings; intubated/CPR
- 19 weaned of ECC, 7 died from refractory respiratory or cardiac failure
- 8 survived to hospital discharge, 11 died from hypoxic brain injury, cerebral bleed, or cardiopulmonary insufficiency

Rewarming from accidental hypothermia by extracorporeal circulation

- 7 survivors neurologically intact – all from the “non-asphyxia” group (partial immersion or exposed to cold environment)
- 1 survivor with a severe neurological deficit from the “asphyxia” group (submersion)
- Patients with a non-asphyxiated deep accidental hypothermia have a reasonable prognosis and should be rewarmed
- Drowned patients with secondary hypothermia have a very poor prognosis

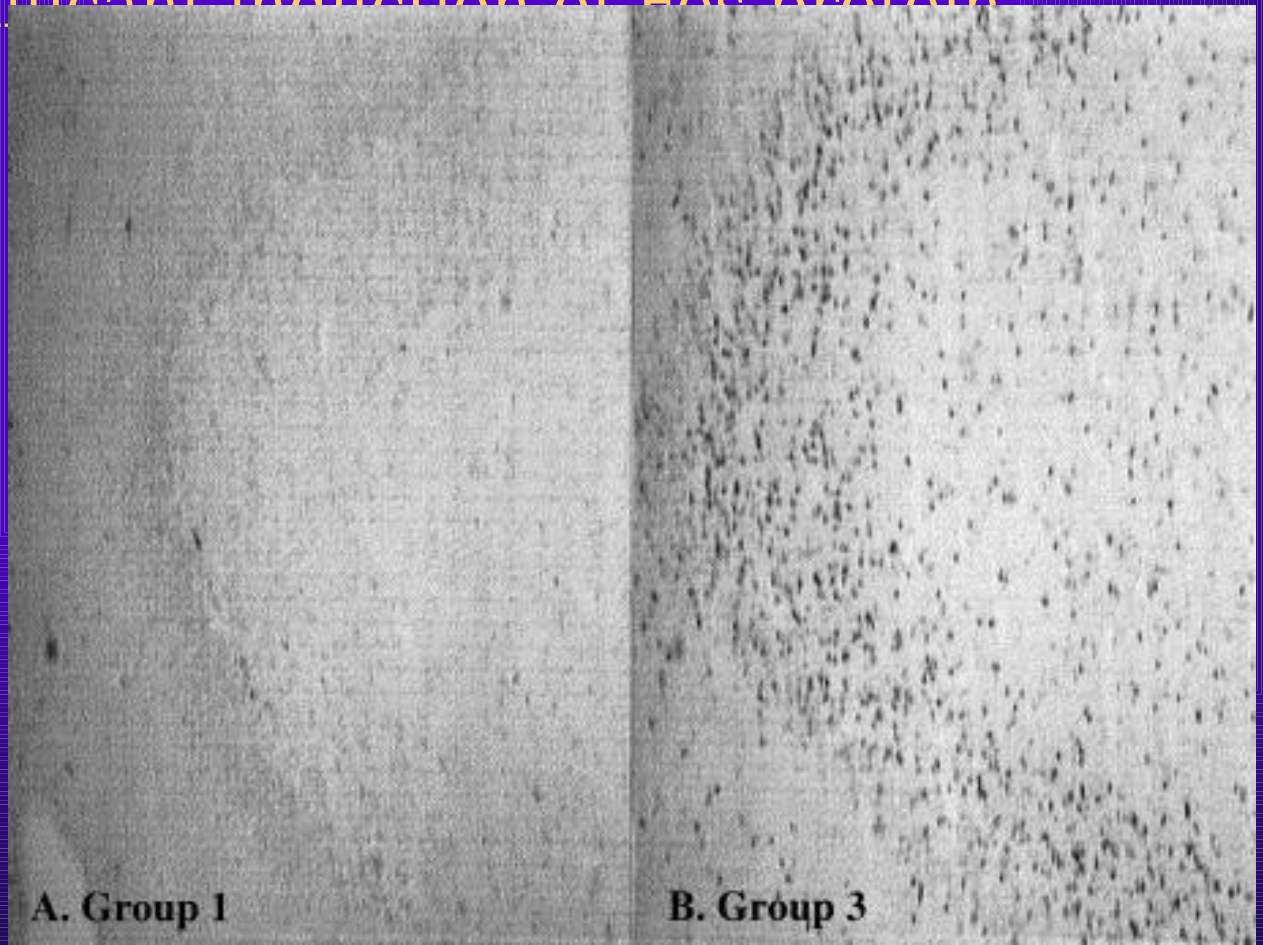
Differential expression of neuronal fos protein after cold water drowning and controlled rewarming.

- Robinson JA – *J Am Coll Surg* – 01 MAR 2004; 198(3): 404-9.
- Use of cardiopulmonary bypass to revive cold water drowning victims.
- Success of resuscitation determined by neurologic outcome.
- Measurement of Fos (protein product of the gene c-fos) is a marker of cerebral injury.

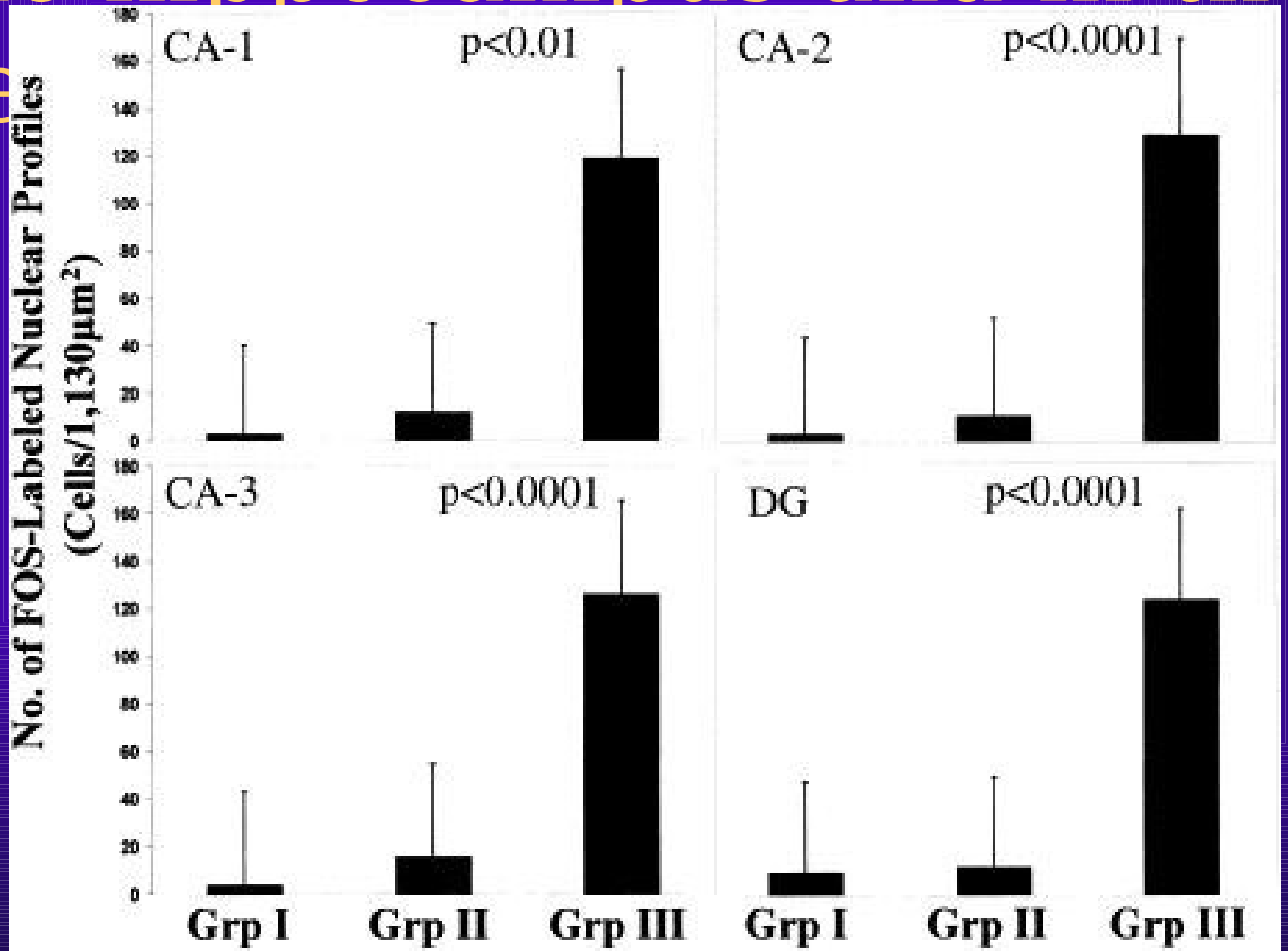
Study design

- 28 infant lambs sedated and ventilated
- Group 1: 2 hours in cold water bath (17 C)
- Group 2: 2 hours on CPB (38 C)
- Group 3: 2 hours in cold water bath followed by 2 hours on CPB
- Lambs euthanized and neuronal Fos was evaluated by immunohistochemical analysis

Photomicrographs from the hippocampus of a group 1 lamb and a group 3 lamb. Expression of Fos protein is demonstrated by the nickel-intensified staining of nuclear antigens. Marked staining in the group 3 specimen indicates significant induction of Fos protein.



Fos protein produced in the CA1, CA2, and CA3 regions of the hippocampus and in the de



Results and conclusions

- Significant induction of Fos-labeled nuclear profiles in group 3 in the hippocampal regions and dentate gyrus compared with groups 1 and 2.
- Isolated exposure to either hypothermia or CPB results in minimal expression of neuronal Fos; the significant induction of Fos in the group 3 animals may represent an ischemic-reperfusion phenomenon.
- Modification of rewarming techniques that minimize Fos expression may improve neurologic outcomes in victims of cold water drowning.

My recs on CPB for rewarming

- Make the decision early upon arrival in ER
- Your brain and heart have to be cold for any protection from ischemia – small children in icy water cool the fastest, followed by adults who cool with circulation present prior to submersion – you have a chance under these circumstances
- If the patient is an adult in cardiopulmonary arrest despite ACLS, hypothermic, GCS of 3, fixed and dilated pupils, and submerged for over an hour – do not start CPB

Prevention

- Swimming, rescue, and lifesaving skills including CPR needed for those near water
- Health and training appropriate for the sport
- Attention to weather, location, environment
- Swimming pools enclosed by a 5-foot fence with a self-closing and latching lock. Lifesaving equipment close at hand.
- Parent supervision
- No alcohol in a marine environment (Auerbach)

Ocean safety

- Swim near lifeguard
- Swim away from rocks, piers, stakes
- Avoid rip currents. If caught, swim transversely to shore.
- Don’t drown yourself attempting a rescue
- Do not dive in shallow water
- Keep away from marine animals
- Read and follow warning signs

(Orlowski)

Pool safety

- Close adult supervision – never leave alone
- Fence/gate/latch
- Turn off pump filters when using pool
- Keep a portable phone poolside so you don’t have to leave to answer
- Swimming lessons (Orlowski)

When in the stream, by accident is found
A pallid body of the recent drown’d,
Tho’ ev’ry sign of life is wholly fled,
And all are ready to pronounce it dead,
More patient thou, with ardour persevere
Four hours at least’ the gen’rous heart will fear,
To quit its charge, too soon, in dark despair;
Will ply each mean, and watch th’ effect with care
For should the smallest spark of life remain
Life’s genial head may kindle bright again.

“The Cheap Magazine” as noted by Scherlis L. Poetical version of the rules of the Humane Society for recovering drowned persons. Crit Care Med 1981; 9: 430-432

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Drowning is not the only cold water immersion injury